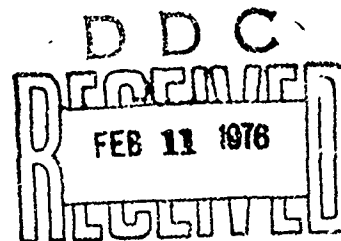# NSWC TECHNICAL REPORT

WHITE OAK LABORATORY

DEPTH SCALING OF UNDERWATER EXPLOSION SOURCE LEVELS

BY
Joel B. Gaspin

2 DECEMBER 1975

NAVAL SURFACE WEAPONS CENTER
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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSWC/WOL/TR-75-182	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* DEPTH SCALING OF UNDERWATER EXPLOSION SOURCE LEVELS.		5. TYPE OF REPORT & PERIOD COVERED Final rept.,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Joel B. Gaspin		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Surface Weapons Center White Oak Laboratory White Oak, Silver Spring, Maryland 20910		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 5WR13
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE 2 December 1975
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

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17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Source Level
underwater explosions as acoustic sources
depth scaling

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A new method of depth scaling underwater explosion source levels
is presented. The method involves modification of the negative
phases of the explosion pressure-time history. The method is
shown to be accurate for depth change of an order of magnitude,
and frequencies greater than twice the bubble pulse fundamental
frequency. This technique is most easily applied to digital
data, and is useful in situations where only a minimal investment

of time and effort is possible.   Scaling by means of a constant
time (or frequency) scale factor is shown to be inadequate for
large depth changes.
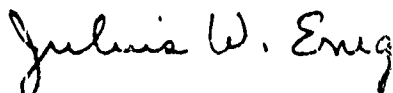
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DEPTH SCALING OF UNDERWATER EXPLOSION SOURCE LEVELS

The proper use of underwater explosions as acoustic sources in long
range sound propagation experiments is dependent upon an accurate
method of estimating source energy levels. One method has been to
construct a digital pressure-time curve, by semi-empirical methods,
and obtain its spectral energy. This method is time consuming,
however, and may not be warranted for a limited study.

A new method of scaling the pressure history is described in this
report. This method permits rapid approximation of the spectrum to be
made from a known explosion pressure-time history for changes in charge
depth of up to 50 percent. The work was supported by the Office of
Naval Research.

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ILLUSTRATIONS

1. INTRODUCTION

The problem of scaling narrow band explosion source spectra from
one burst depth to another, for conditions for which no data is
available, has long been with us. For relatively deep explosions,
Christian[1] has presented a family of scaled source spectra curves
which may be used to obtain octave band energy levels. These curves
provide source energy levels for explosions at burst depths of from
120 to 22,000 feet, and are based on actual data.* At shallower
depths, the technique of Gaspin and Shuler[2] may be used. This
involves the construction of a digital pressure-time history for the
condition of interest, and calculation of the energy spectra by fast
Fourier transform techniques. While this method has been widely
accepted for applications in which data is not available, it requires
a substantial input of time and effort.

There is a need, therefore, for a quick, "short cut" scaling
method, to be used on occasions when only an extremely limited effort
may be put forth, to scale a known source spectrum at a given depth
to another depth at which no data is available. One frequently used
technique has been to scale the pressure by a constant time factor
before spectral analysis. Equivalent to this is the application of
a constant factor to the frequency scale after transformation.
Gaspin and Shuler used this scaling technique to model the effect
of small changes in burst depth on the energy spectrum. This simple
linear approach was deemed adequate for this application, with depth
changes of ±10 percent and less.

In connection with a recent study, a source energy level was
required for a condition which called for scaling a 50 percent change
in burst depth. The linear approach proved to be inadequate for this
situation. A new method of depth scaling explosion pressure-time (p-t)
histories has been developed. The method involves a convenient
modification of the underpressure phases of an available p-t curve,
and has been shown adequate for depth changes of an order of magnitude.
P-t data, in digital form, may be depth scaled with a minimum of
effort by using this method.

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1. Christian, E. A., "Source Levels for Deep Underwater Explosions,"
   J. Acoust. Soc. America, 42, 905 (L), 1967
* The curves for depths of 500-feet and less are not based entirely
   on data.
2. Gaspin, J. B. and Shuler, V. K., "Source Levels of Shallow
   Underwater Explosions," Naval Ordnance Laboratory Technical Report
   NOLTR 71-160, 13 Oct 1971

This new scaling technique is detailed below, and its limitations discussed. As an application, the Gaspin and Shuler p-t curve for 3-pounds of TNT at a 60-foot burst depth is scaled to a 30-foot burst depth. All calculations in this report are for a 100-yard reference range.

2. USE OF A LINEAR TIME SCALE FACTOR

Most of the significant times in the p-t history are given by

$$T = \frac{KW^{1/3}}{Z^{5/6}}$$

where W is the charge weight (pounds), Z is the hydrostatic head (= burst depth + 33 feet of H_2O) and K is a constant (see Table 2 of reference 2). The times so represented are the first through fourth bubble pulse periods, the duration of the first and second positive phases, and the duration of the first negative phase. Due to this situation, it has been common to scale from one burst depth to another by using a time scale factor of

$$S = \left(\frac{D_1 + 33}{D_2 + 33}\right)^{5/6} ,$$

where D_1 and D_2 are the initial and desired burst depths in feet. The inverse of S may be used with the same effect in the frequency domain.

One significant time that does not scale in this manner is the shock wave time constant, θ. The time constant is a function of charge weight and range only, and does not vary with burst depth. Additionally, the widths of all the positive pulses change more slowly with depth than $Z^{5/6}$. Scaling to a shallower depth using a constant time scale factor tends to increase the impulse in the shock wave and bubble pulses unrealistically. Linear scaling, therefore, introduces a certain distortion into the p-t curve, and consequently, into the spectral energy. This technique, however, has the advantage of extreme ease of application. Given a p-t curve in digital form, one may depth scale by merely multiplying the time increment between successive data points by "S".

In a recent application, a source level for a 3-pound charge at a 30-foot depth of burst (DOB) was needed. As the effort was too limited in scope to generate a new p-t curve by the method of Gaspin and Shuler (G&S), we hoped to scale their 3-pound 60-foot DOB curve to a 30-foot DOB using a linear scale factor. Since it had never been used to scale such a large change in depth ($\sim$ 50 percent), an internal consistency check on the scaling method was made.

The 1.8-pound -- 800-foot DOB p-t curve of reference 2 was scaled to a burst depth of 300-feet using a time scale factor of 2.15

$(= (\frac{800 + 33}{300 + 33})^{5/6})$. If the scaling method were adequate, the energy

spectrum should be equal to that from the 300-foot curve of that reference. The results of this comparison are given in Table 1.

Table 1. Depth Scaling With A Linear Time Factor
1.8-Pounds TNT

Frequency Band (Hz)	Energy Flux Density (dB re 1 erg/cm^2/Hz)		
	800-foot → 300-foot	300-foot G&S	Δ
45-90	17.8	14.4	3.4
89-190	15.3	12.1	3.2
178-354	12.4	9.0	3.4
356-707	9.4	6.1	3.3

The scaled energy values are about 3.3 dB greater than those from the 300-foot curve. Other conditions scaled in this manner also were unacceptably inaccurate. The inacurracy is caused by the incorrect scaling of θ, the pulse widths, and the impulse in the positive pulses. Since generating a new p-t curve by the method of reference 2 was too lengthy a procedure for this very limited study, a new scaling technique was sought which could at least scale one p-t curve accurately into another.

3. NEGATIVE PRESSURE PHASE DURATION SCALING

A more correct scaling method would involve scaling the bubble pulse periods by $z^{5/6}$ while leaving θ, the bubble pulse widths and the positive impulse unchanged. This may be accomplished by changing the durations of the negative phases of the p-t curve.

In a previously unpublished study, Verna K. Shuler, of the Naval Surface Weapons Center, determined that the effect of eliminating the negative phases of the p-t history was limited to frequencies of several times the bubble pulse fundamental frequency f_b, and lower. In the application at hand, 3-pounds at 30-foot DOB, f_b is ~6 Hz. Since we were only interested in frequencies greater than 30 Hz, the negative phases were available for modification.

The following discussion concerns scaling to shallower burst depths. Since the effect of making the burst depth shallower is to increase the bubble periods, our approach was to lengthen the negative phases of the p-t curve in order to achieve the desired bubble periods. The spacing of the positive pulses is thereby increased, but their shapes and impulses remain unchanged. Secondary time parameters, such as the positive phase durations, and ambient pressure crossing times, are not scaled.

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The lengthening of the negative phases was easily achieved by breaking into the p-t curve at the minima of the negative phases, and inserting the required number of data points with pressures equal to those at the minima. Since the shape of the negative phase is roughly a very flat parabola, the effect of this lengthening was to increase the flatness by adding a plateau of constant amplitude. No discontinuities are introduced into the p-t history by this process. Figure 1 illustrates the process. In Figure 1a is the original p-t curve, from reference 2, for a 1.8-pound charge at an 800-foot DOB. Figure 1b shows this curve with the negative phase lengthened so as to scale 1.8-pounds at 300-foot DOB, and Figure 1c shows the original Gaspin and Shuler curve for this condition. The main features of curves 1b and 1c compare quite closely. Examination of the first negative phase shows that the scaled 300-foot curve has more energy than the original. The negative amplitude is well modelled, but the descent is steeper and the plateau longer in the scaled curve. This is also true of the second, third and fourth negative phases. The spacing and shape of the bubble pulse are closely matched.

The energy flux density spectra for the scaled and original 300-foot curves are shown in Figure 2. For frequencies below the bubble fundamental, $\sim$25 Hz, the agreement is poor. Between 25 and 50 Hz the curves become more similar. Above 50 Hz, $\sim$2 f_b, the agreement is quite good, with the spacing and shape of the lobes, as well as the energy levels, generally well modelled.

The discrepancies for frequencies below 2 f_b are due to the inaccuracy in modelling the shape of the negative phases. The additional energy apparent in the negative phases of Figure 1b, transforms into an excess of very low frequency energy in the scaled spectrum of Figure 2.

A similar comparison for a 3-pound charge scaled from 500-feet DOB to 60-feet DOB is shown in Figure 3. Again, there are large differences between the original and scaled spectra at frequencies up to f_b (in this case, $\sim$7 Hz). Between f_b and 2f_b, the differences become smaller. Above 2f_b, only small differences persist. What discrepancies there are above 2f_b tend to wash out when the energy is integrated in octave bands, as will be demonstrated in the next section.

4. ACCURACY OF THE METHOD

The accuracy of this new scaling method may be judged by scaling one p-t curve into another known curve, and comparing the integrated energy spectra. This is an internal consistency check for the scheme by which the original p-t curves were constructed as well. The p-t curves available from Gaspin and Shuler's work are 1.8-pounds at burst depths of 800, 300 and 60-feet, and 3-pounds at burst depths of 500 and 60-feet. Each of the deeper curves for each charge weight was scaled to each of the shallower depths. The curves were then transformed using a fast Fourier transform program, and integrated in octave

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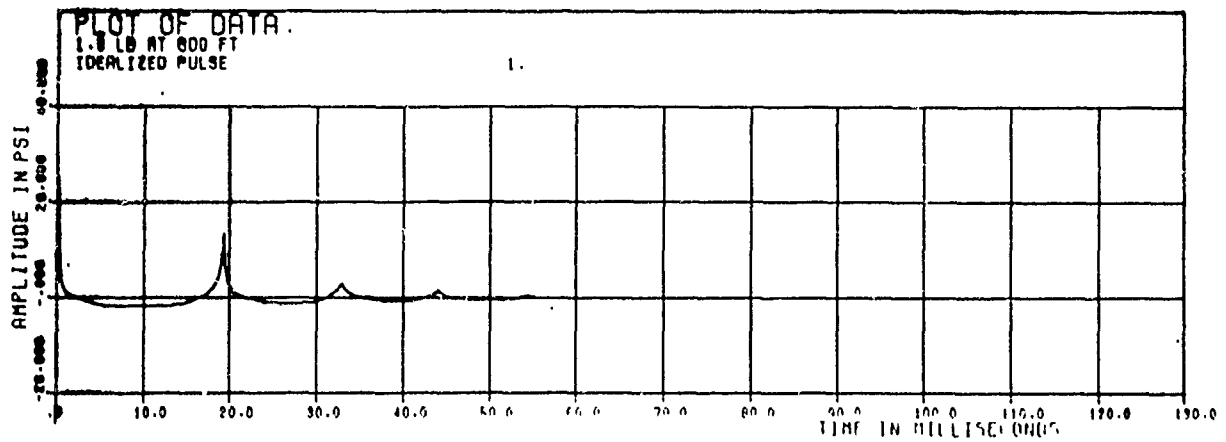
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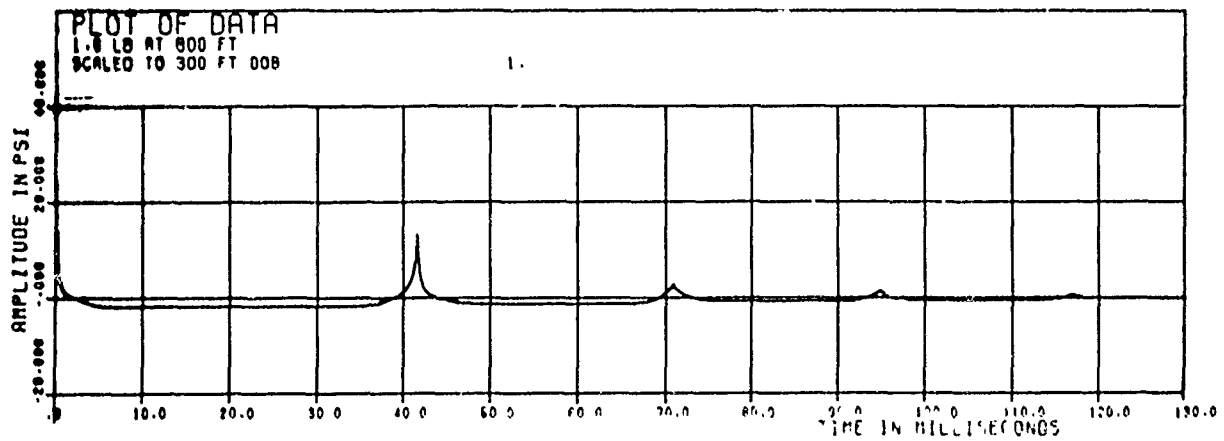
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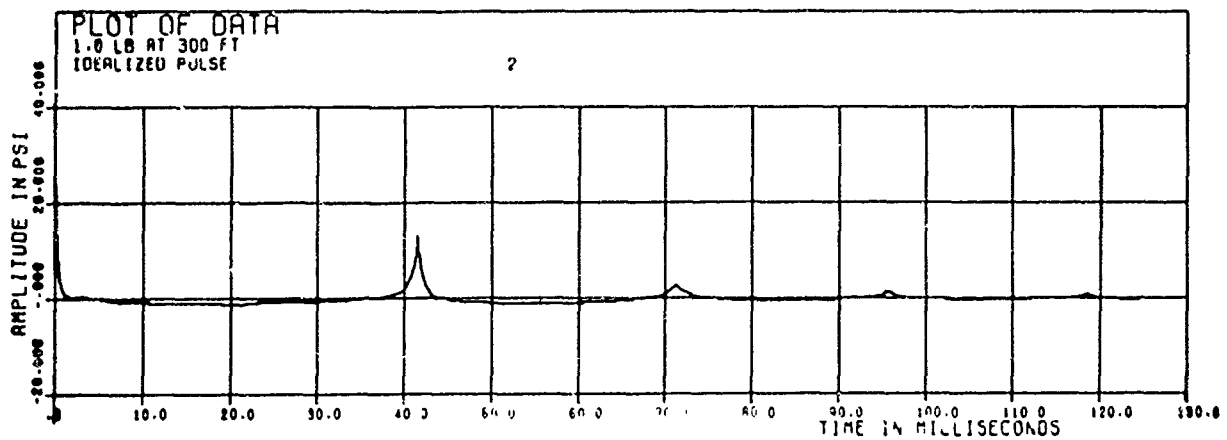
(c)

FIG. 1   PRESSURE—TIME CURVES

FIG. 2 ORIGINAL AND SCALED ENERGY SPECTRA
1.8 LB AT 300 FT BURST DEPTH

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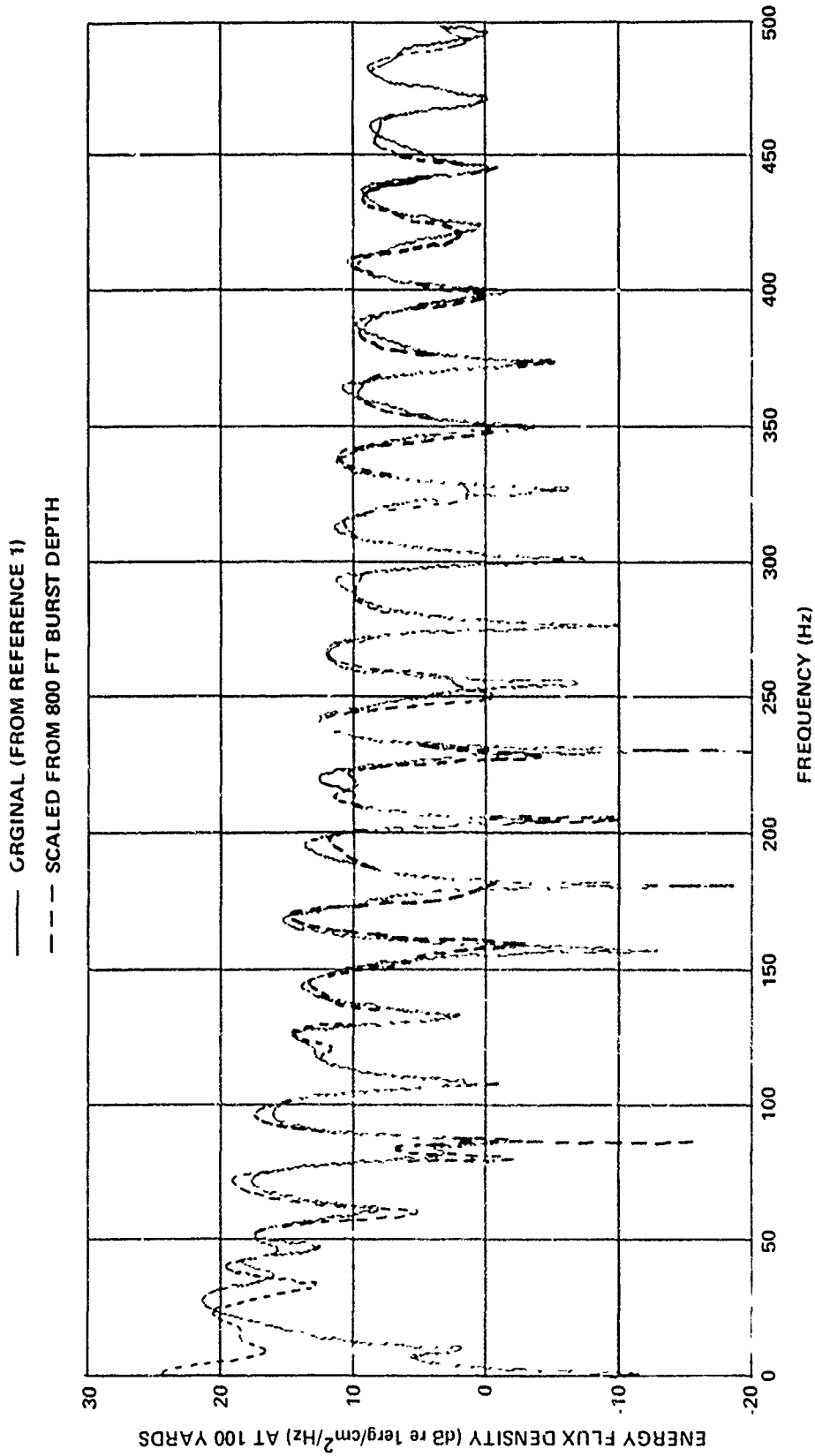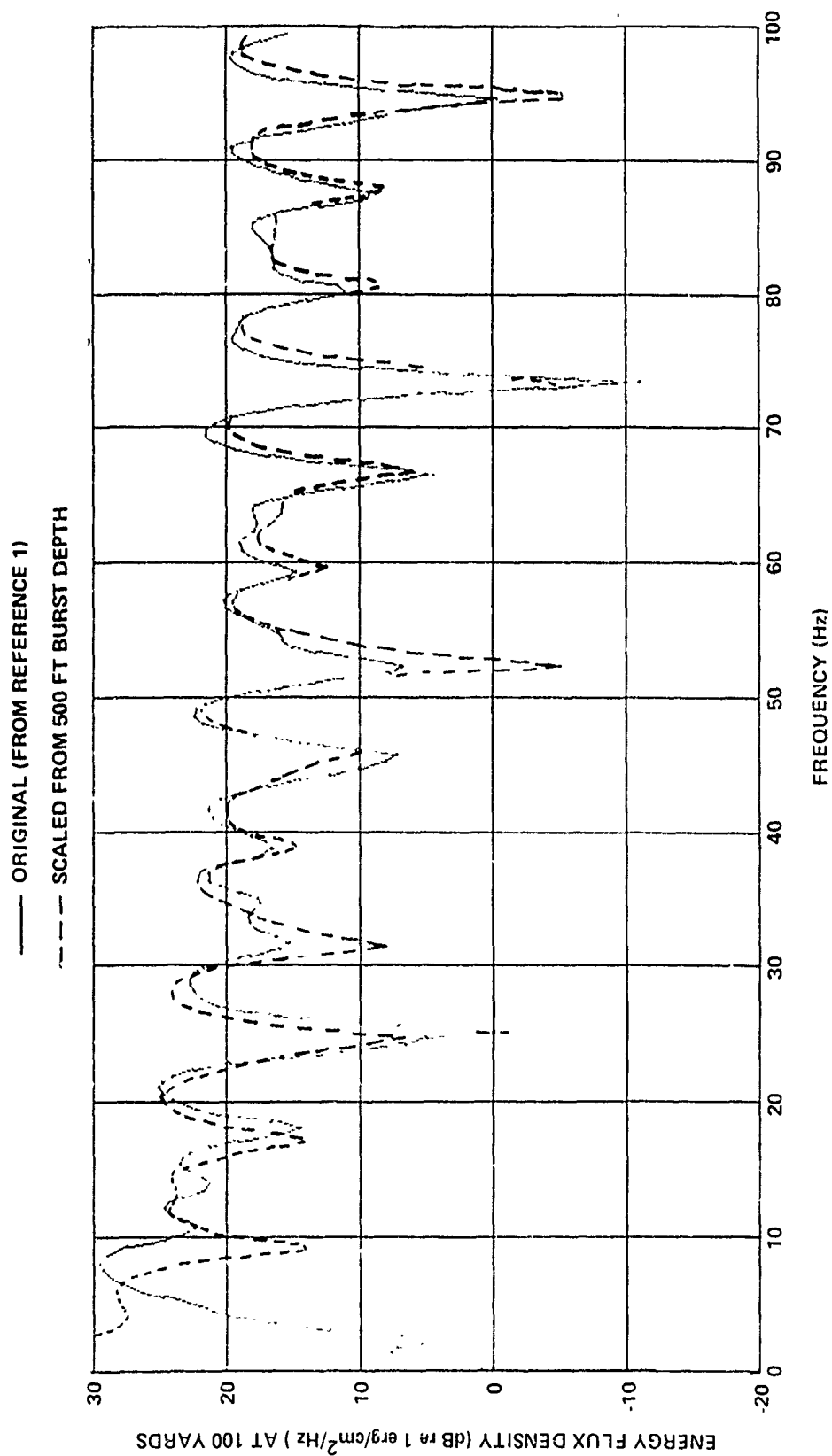FIG. 3   ORIGINAL AND SCALED ENERGY SPECTRA
3 LB AT 60 FT BURST DEPTH

bands. The energy of each scaled curve was then compared to the original G&S energy values. The results of these comparisons are shown in Table 2.

Table 2. Differences Between Scaled and
Original Source Levels

$E_{scaled} - E_{original}$ (dB re 1 erg/cm^2/Hz)

Charge Weight (Pounds)	1.8	1.8	1.8	3
Original → Scaled Depth (Feet)	800 → 300	800 → 60	300 → 60	500 → 60
$(Z_1/Z_2)^{5/6}$ (= S)	2.1	6.2	2.9	4.3
Frequency Band (Hz)				
45 - 90	0.9	0.7	0.2	1.0
89 - 180	0.2	0.0	0.2	0.7
178 - 354	-0.5	0.1	0.7	0.0
356 - 707	0.2	0.9	0.6	0.7
713 - 1403	0.7	0.4	0.8	0.3
1425 - 2806	0.6	0.9	0.5	0.1
2806 - 5612	0.3	0.2	0.9	0.0

RMS Difference = 0.6 dB

The absolute value of each of the differences was less than or equal to 1.0 dB. Previous experience with source level computations indicates that this is excellent agreement. The RMS deviation was 0.6 dB. All the differences, save one, were positive, indicating a systematic error. This comparison indicates that the scaling method is acceptably accurate for depth scaling factors, S, of up to 6.2. Note that this scaling was only done from deeper to shallower depths.

As an example of the use of this method, the source level for a 3-pound charge of TNT at a 30-foot burst depth was generated by scaling the 60-foot DOB curve of reference 2. The energy was integrated in octave bands which were required for a specific application. The results are given in Table 3.

Table 3: Source Level For 3-Pounds at 30-Foot
Burst Depth (Reference Range = 100 Yards)

Frequency Band (Hz)	Energy Flux Density (dB re 1 erg/cm^2/Hz)
30 – 60	18.8
50 – 100	17.1
100 – 200	14.5
200 – 400	11.1
400 – 800	7.4
800 – 1600	4.7
1600 – 3200	0.9

Several factors enter into the accuracy of this calculation:

    a. The internal consistency of the scaling method. Table 2 indicates that the RMS deviation due to this is ~0.6 dB. In other words, the scaled source level may generally be expected to be within ~1 dB of one generated by the Gaspin and Shuler method, for that depth.

    b. Extrapolation of p-t parameters. The data from which the p-t parameters were derived was from burst depths of 500-feet and greater.[3] Gaspin and Shuler extrapolated to 60-feet, and we have further extrapolated to 30-feet. This extrapolation remains to be checked against experimental data.

    c. Bubble migration. It is not within the scope of this study to investigate the effects of migration of the explosion bubble toward the water surface. Migration would be more pronounced for a 3-pound, 30-foot DOB shot than for any of the original G&S conditions, but the effect of this on the source level remains to be evaluated. The effect of migration is to decrease the energy in the bubble pulses, and therefore, to lower the source level at low frequencies. Since the negative phase duration scaling discussed here gives source levels which are systematically high, this may tend to cancel out some of the decrease due to migration.

The total effect of these factors can not be accurately estimated at this time. Certainly, source levels generated by this method should be considered accurate to no better than ±1 dB, as a lower limit.

5. SUMMARY AND CONCLUSIONS

Depth scaling underwater explosion pressure-time (p-t) histories by use of a linear time scale factor depending on the 5/6 power of

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3. Slifko, J. P., "Pressure Pulse Characteristics of Deep Explosions as Functions of Depth and Range," Naval Ordnance Laboratory Technical Report NOLTR 67-87, 21 Sep 1967

the hydrostatic head is not adequate for large burst depth changes. The inaccuracy is caused by the incorrect scaling of the shock wave decay constant, which is independent of burst depth, and the unrealistically large modifications imposed on the bubble pulse shapes and the positive impulse.

Scaling the duration of only the negative pressure phases of the explosion signal is an accurate and easily applied method of depth scaling digital waveforms. At frequencies greater than twice the bubble fundamental, this scaling method is internally consistent; one known p-t curve scaled into another, shallower p-t curve by this method, will yield spectral energy levels agreeing within 1 dB in octave bands. This holds true for depth changes of an order of magnitude or less. Possible sources of error in scaling the spectra to shallower burst depths are:

      a. the extrapolation of deep to shallow pressure parameters which remains to be checked against experimental data, and

      b. the effect of bubble migration, which becomes more pronounced at shallower burst depths.

The overall accuracy of source levels obtained by scaling the negative phases is no better than ± 1 dB, and several dB may be more realistic.

It is recommended that depth scaling of explosion p-t curves for the purpose of obtaining spectral energy, be performed by the method of this report, when the frequencies of interest are greater than twice the bubble fundamental. Comparison of source levels obtained in this way with high quality, shallow experimental data, is necessary to determine the accuracy of this, or any other approach to the calculation of source levels.

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